HIGH TEMPERATURE PHASE EQUILIBRIA IN THE ENSTATITE CHONDRITE SYSTEM

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Siliceous chondrules and lithic fragments that could not be derived through normal igneous processes seem to occur commonly in enstatite chondrites and unequilibrated H-chondrites: these include chondrules of almost pure SiO_2 in Qingzhen (Nagahara and El-Goresy, 1984) and Kota-Kota (Leitch and Smith, 1982) and lithic fragments and chondrules whose primary phase is SiO_2 in Qingzhen (Nagahara and El-Goresy, 1984) and chondrules whose primary phase is SiO_2 in several H-chondrites (Brigham *et al.*, 1982). Bulk compositions of enstatite chondrites projected onto the system Fe - Mg_2SiO_4 - SiO_2 lie within or very close to the primary phase field of SiO_2. Since enstatite is the major siliceous component of these meteorites, the remaining siliceous components must be in the primary phase field of SiO_2 in order to produce such highly siliceous bulk compositions. Because it is so difficult to imagine igneous solid/liquid fractionation processes that could produce these high-SiO_2 components, I suggest they were derived by vapor/liquid fractionation during condensation in the primitive solar nebula. In such a case, phase relations in the system Fe - Mg_2SiO_4 - SiO_2 suggest that these particles, in condensing directly from vapor, passed through conditions in which two or three immiscible liquids were produced (for convenience, the additional sulfide liquid is ignored). The system contains three intersecting 2-liquid domes which envelop an underlying 3-liquid volume. As total pressure in this system decreases, the vaporous surface intersects the 2-liquid domes at lower and lower temperatures, eventually intersecting the 3-liquid volume also. At even lower total pressures for these compositions, crystalline cristobalite would condense directly from the vapor, accompanied by two immiscible liquids. Textural relations in some of the enstatite chondrite particles suggest that temperatures and pressures were high enough so that at least two of the liquids considered here were present. Composition of the high-silica phase often suggests that it was present as a third liquid. This would require rather high temperatures and pressures in that part of the primitive solar nebula where these particles were produced.

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ANOMALOUS SILVER IN SULFIDE NODULES

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Excesses of ^{107}Ag ($^{107}Ag^*$) correlated with Pd/Ag have been found in iron meteorites of IVA, IVB and IIIAB groups, and is inferred to be the daughter of extinct ^{107}Pd (τ = 9.4 m.y.) (Kelly and Wasserburg, 1978; Kaiser and Wasserberg, 1983; Chen and Wasserburg, 1983, 1984). However the Pd/Ag systematics involving the coexisting metal and sulfide phases of Santa Clara (IVB) and Gibeon (IVA) do not show a good internal isochron. These meterorites have undergone shock melting and later heating and forging which may have redistributed Pd and Ag and confused the Pd-Ag systematics (El Goresy *et al.*, 1984).

We have undertaken a detailed study of the sulfide inclusions and the adjacent metal in Gibeon in order to understand the Pd-Ag systematics in these phases. Three samples of Gibeon, ASU Lion River, USNM #3187, and USNM #679 werer investigated. The metal phase shows a wide range of $^{107}Ag/^{109}Ag$ (1.54 to 9.23) and $^{108}Pd/^{109}Ag$ (1.8×10^4 to 3.2×10^5). These data plot close to a line with a slope corresponding to $^{107}Ag^*/^{108}Pd = 2.3 \times 10^{-5}$ and an initial $^{107}Ag/^{109}Ag = 1.13$ which is greater than the normal value of 1.09. The Pd-Ag results on sulfides from USNM #3187 and ASU Lion River show greater $^{107}Ag/^{109}Ag$ values in the "interior" cores (1.19 to 1.28) than in the HCl leaches (1.10 to 1.12). The ^{108}Pd content in these sulfide nodules range from 4×10^{12} atoms/g (Lion River) to 1.6×10^{15} atoms/g (#3187) which are fully compatible with the proportion of metal taken up in the heavily shocked troilite-rich nodules

(Chen and Wasserburg, 1983). We report here on a new sulfide nodule from USNM #679 which consists of troilite-rich and metal-rich regions. The metal-rich parts of the nodule are fine grained material of eutectic texture which have flowed into the fine grained, more sulfide rich center. The results from the troilite-rich region are similar to those from the pure FeS sample of Lion River. The $^{107}Ag/^{109}Ag$ in the metal-rich region is 1.18 and the ^{108}Pd is 10^{15} atoms/g which is compatible with the presence of ~ 20% metal.

The sulfide nodules contain Ag which is isotopically very heterogeneous. The presence of $^{107}Ag^*$ in the nodules is interpreted to result from limited diffusion of $^{107}Ag^*$ from metal to the sulfide during rapid cooling (> 150°C/my) or due to admixtures of metal and sulfide during shock melting. To test for evidence that $^{107}Ag^*$ had diffused from the adjacent metal to the sulfide nodule we analyzed a piece of metal from the contact zone with the nodule. The metal sample represented ~ 1 cm thick region of the contact zone. The whole sample was first leached in hot aqua regia (leach-1) and then only the side which was in contact with the nodule was leached (leach-2). The interior core was then dissolved and analyzed. The $^{107}Ag/^{109}Ag$ ratios increase from 1.1 in leach-1 to 1.18 in leach-2 to 4.55 in the core, while $^{108}Pd/^{109}Ag$ ratios increase from 511 to 2000 and to 1.43×10^5. The $^{107}Ag^*$ content changes from 1.07×10^{11} to 2.27×10^{11} and to 1.35×10^{11} atoms/g. The Pd-Ag data for the core and total sample plot on the isochron for Gibeon and apparently did not show any preferential mobilities of Pd or Ag at the center of the contact zone on the sample scale. The Ag isotopic peculiarities of the "sulfide" phase for the IVAB meteorites and the transport of $^{107}Ag^*$ is apparently complex and not readily explained. However, the "metal" phase appears to be well behaved and shows a remarkably coherent behavior between $^{107}Ag^*$ and Pd.

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STRUCTURAL DEVELOPMENT IN THE SANTA CATHARINA METEORITE

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The Santa Catharina, Brazil, meteorite is a deeply weathered, chemically anomalous ataxite with the third highest Ni value on record (~ 34%). Mössbauer and X-ray data have led to the suggestion that the meteorite transformed at very low temperatures to major amounts of the ordered NiFe mineral tetrataenite and a martensitic phase, in effect, to massive 'cloudy taenite'. This metallographic study sought confirmation of that idea.

Available metal-rich nuggets of Santa Catharina appear to have been originally single crystals of taenite in the few centimeter size range, separated from each other by grain boundaries occupied by troilite and schreibersite. Metallographic and electron microprobe data, and the Fe-Ni-P phase diagram, allow one to postulate the following cooling and structural development history: (1) single crystal taenite formed at high temperature, (2) phosphate formed within the taenite and grain boundary schreibersite formed at interfaces with troilite or with other taenite crystals, (3) schreibersite began to precipitate within taenite or about 650°C, (4) at about 450°C the meteorite entered the three phase field and kamacite precipitated and started growing, (5) cooling continued down to at least 350°C. This last conclusion is based on high Ni values in schreibersite at kamacite interfaces. These values are also associated with dramatic Ni diffusion gradients within schreibersite that are comparable to those commonly observed in taenite lamellae.

Terrestrial weathering has destroyed much of the Santa Catharina mass and has severely modified all of the specimens available to me. Oxide formation along grain boundaries and cracks ranges from mild to severe. Oxidation within taenite crystals has penetrated along crystallographic planes into the deep interior. Areas of incipient corrosion within taenite typically contain from 4 to 6% O, about 0.1% Cl, and 42 to 48% Ni. Areas of more advanced oxide formation contain similar levels of Ni and Fe, slightly more O, and no detectable Cl. It is suspected that Cl plays a role in the corrosion process but is not retained in the fully developed corrosion product.